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Full Length Research Paper

Experimental and Numerical Study of Thermal performance of a Building Roof including Phase Change Material (PCM) for Thermal Mangement

Mushtaq T. H*, Ahmed Q. M, Hasanain M.H***.**

*Assist lecture
**Assist. Prof. technical college Baghdad,
***Lecture university technology Baghdad .

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In this paper a detailed study on the thermal performance of a phase change material based on thermal storage for energy conservation in building is presented .An experimental set up consisting of two identical test rooms has been constructed to study the effect of having a PCM panel on the roof of the building .One, room is constructed without PCM forcomparison purposes. The melting temperature of PCM is in the range of (36.7-37)^{0}C.Several simulation runs were made for the average ambient conditions and for various other parameters of interest. As the PCM has low thermal conductivity it offers the resistance for the heat flow and heat transfer was reduced by 46.71% compared to the roof without PCM .

Keyword : pcm , compared roof , energy of building.

BACKGROUND

The energy required for heating and cooling of buildings plays an important role in all countries. In many countries heating/ cooling and air-conditioning systems are used in many commercial and residential buildings. Due to increase in energy demands of these systems, an appropriate insulation of buildings, such as walls, roofs and floors is important in reducing the rate of heat flowing to buildings in summer and winter. Selecting a proper insulation material by considering its thermal properties in each weather conditions should be expected to favor the economics of the buildings. In addition, to make a suitable lagging time to heat flux entering the buildings by storing energy is another way to control indoor air quality. The storage of energy can be done in the form of sensible and latent. In sensible heat storage (SHS), energy can be stored only by changing the temperature of the solid or liquid. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The mass of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material (Atul et al., 2009). In latent form of energy storage, energy is stored by changing the material phase and using of latent heat. The energy is stored in Phase Change Material (PCM) by latent form.

Corresponding Author Email: dr.nagham_mj@yahoo.com

Moreover, the thermal conductivity of PCM is usually less than bricks. Therefore, PCMs can play both as insulation and alsoas a storage materials. Due to these advantages the use of PCM in building material is considered in the past decade. The characteristics of PCMs make them suitable for use in energy conservation.

Development of PCM for cooling of buildings

A phase change material (PCM)is a substance with a high heat of fusion which, melted and solidified at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units. (Kenisarin and Mahkamov, 2007) The PCM can be used as natural heat and cold sources or manmade heat or cold sources. In any case, storage of heat or cold is necessary to match availability and demand with respect to time. There are three different ways to use PCMs for heating and cooling of buildings: (Ravikumar and Pss.srinivasan, 2008).

- In building walls;
- In building components other than walls i.e. in ceilings and floors;
- In separate heat or cold stores.

Classification and properties of PCMs

Materials to be used for phase change thermal energy storage must have a large latent heat and high thermal conductivity. They should have a melting temperature lying in the practical range of operation, melt congruently with minimum sub cooling and be chemically stable, low in cost, nontoxic and non-corrosive. Materials that have been studied during the last 40 years are hydrated salts, paraffin waxes, fatty acids and eutectics of organic and non-organic compounds (Mohammed et al., 2004) as shown in Fig (1) (Pasupathy et al., 2008).

There are several promising developments going on in the field of application of PCMs for heating and cooling of building:

Heim and Clarke(6) Show the effect of latent heat storage on the thermal behavior of the building. This effect did not cause a considerable reduction in diurnal temperature fluctuation. Lamberg and K.sire(7) The analytical solution is compared with numerical results using same initial and boundary values and material properties. The analytical model is also compared with three different cases to predict the influences of the basic heat transfer modes on the results.Carbonari, M. De Grassi et al.(8) evaluating the energetic performances of such panels, which make them suitable for use in different climatic contexts or in different elements of buildings. Esam M. Alawadhi (9) indicate that the heat flux at the indoor space can be reduced by 17.55% when three PCM cylinders are introduced, placed at the centerline of the bricks. Mandilaras, M. Founti,(10) shows the ability of the new materials to stabilize their temperature near the melting range of the PCM(25 °C – 30 °C), and potentially reduce heat losses of a building. A.F. Rudd,(11) shown that the concept is workable on a large scale and that phase-change material can be successfully integrated and distributed within a building with a significant thermal storage effect. Obtain the magnitude of storage required). Jørgen Rose et al(12) a case study has presented an example showing how the module can be used for optimizing indoor climate in a room using PCM. Samira etal (13) show a significant reduction in maximum entering heat flux to building about 32.8% depending on PCM quantity. Nasrul Amri Mohd Amin,et al(14) showed that, when optimized, a PCM system can deliver a true energy storage density between 53% and 83% of the latent energy density of the PCM.

The above numerical and experimental studies have emphasized the importance of PCMs a good and efficient way for energy storage . In the numerical study, the researchers have used the CFD technique and ESP-r program in most of their work and in the experiments they have used different kinds of PCM in the walls and ceiling .and in different climates. In the present study the focused will be on the design and installation of a suitable PCM in the roof of a building to study and analysis its effect on the comfortable zone in the building.

Mathematical formulation

The physical system considered is aluminum panel filled with PCM placed in between the roof top slab and the bottom concrete slab, which form the roof of the PCM room. In each cycle, during the charging process (sunshine hours), the PCM in the roof change its phase from solid to liquid. During the discharging process (night hours), the PCM changes its phase from liquid to solid (solidification) by rejecting its heat to the ambient and to the air inside the room. This cycle continues every day. The composite wall is initially maintained at a uniform temperature "T_i". The boundary condition on the outer surface of roof is considered due to the combine effect of radiation and convection. In order to consider the radiation effect, the average monthly solar radiation heat flux available in thecondition of Baghdad Iraq is used for every one-hour. For convection, the heat transfer coefficient (h) value on the outer surface is calculated based on the prevailing velocity of the wind using the heat transfer coefficient correlation.[(Clear et al., 2001). {$\overline{Nu}$=0.664 $(Re)^{1/2}$ $(Pr)^{1/3}$}The boundary condition on the inner surface of the concrete slab is considered to be

natural convection. As the temperature difference between the room and the wall is very small, most of the earlier researchers have approximated the bottom wall as insulated. The heat transfer coefficient (h) inside room can be calculated by {Nu=0.54 (Gr.Pr)$^{0.25}$}For the mathematical formulation of the above-mentioned problem shown in Figs (2) and (3) the following assumptions are made: (i) The heat conduction in the composite wall is one-dimensional and the end effects are neglected.
(ii) The thermal conductivity of the concrete slab and the roof top slab are considered constant and do not vary with temperature.
(iii) The PCM is homogeneous and isotropic.
(iv) The convection effect in the molten PCM is neglected.
(v) The interfacial resistances are negligible.
(vi) The 'c_p' value of the PCM in the panel is considered as follows:

$$T < T_m - \Delta T cp = cp_s$$
$$T > T_m + \Delta T cp = cp_l$$
$$T_m - \Delta T < T < T_m + \Delta T cp = h_{sl}/2\Delta T$$

where 'c_p' is the specific heat capacity, h_{sl} is the enthalpy change of solid–liquid, ΔT is half of the temperature range over which the phase change occurs and T_m is the temperature about which phase change occurs.
(vii) The latent heat value of the PCM is modeled in the above equation as high sensible heat value during the phase change process. Normally all the PCMs change phase over a range of temperature. In the present model, uniform c_p value is considered during phase change process, though in actual practice, there is variation in c_p value within this small temperature range.In accordance with the above-mentioned assumption, the governing equation and the boundary condition are developed as shown below.

Governing equations

For one dimensional transient heat flow rectangular coordinate system: $\mathrm{k_m}\frac{\partial^2 \mathrm{T_m}}{\partial \mathrm{x}^2} = \frac{\rho_\mathrm{m} \mathrm{cp_m}}{} \frac{\partial \mathrm{T_m}}{\partial \mathrm{t}} \{0 < \mathrm{x} < L\};\ \mathrm{m} = 1,2,3\ldots$ (1) where m=1 for roof top slab m=2 for PCM panel m=3 for bottom concrete slab.The same equation holds good for all three material regions by incorporating suitable k ,ρ ,cp value. In the exterior boundary (x=0) where the floor is exposed to solar radiation ,the boundary condition is,

$$k_1 \frac{\partial \mathrm{T_1}}{\partial_x}|_{\mathrm{x=0}} = \mathrm{q_{rad}} + h_\mathrm{o}(T_\infty - T_{x=0}) \ldots (2)$$

The radiation effect is considered only during sunshine hours .In the bottom layer of the concrete slab x=L ,the boundary condition is

$$+\mathrm{k_3}\frac{\partial \mathrm{T_3}}{\partial_\mathrm{x}}|_{\mathrm{x=L}} = h_i(T_{x=L} - T_{room}) \quad \ldots (3)$$

The instantaneous continuity of heat flux and temperature at the interfaces x=L_1And L_2 is preserved.

Exterior node

The equation for the top volume cell is written as follows (vadaiappa et al., 2006)

$$\left(\frac{\rho_1 c_1 \Delta x_1}{\Delta t} + \frac{f k_1}{\delta x_1} + h_o f\right) T_1 - \frac{f k_1}{\delta x_1} T_2 = h_o f T_\infty + (1 - f)\left[\frac{k_1(T_2 - T_1)}{\delta x_1} - h_o(T_1 - T_\infty)\right] + \frac{\rho_1 C_1 T_1^o}{\Delta t}\Delta x_1 + \alpha q_s + \sigma\left[\alpha T_{sky}^4 - \in T_S^4\right] \ldots (4)$$

Inner node

The equation for any volume cell that is located in between the top and bottom volume cells of a particular material is written as follows [

$$-\frac{f k_m}{\Delta x_m} T_{i+1} + \left[\frac{\rho_m c_m \Delta x_m}{\Delta t} + \frac{f k_m}{\Delta x_m} + \frac{f k_m}{\Delta x_m}\right] T_i - \frac{f k_m}{\Delta x_m} T_i = (1 - f)\left[\frac{k_m(T_{i+1} - T_{-i-1})}{\delta x_m} - \frac{k_m(T_i - T_{i-1})}{\delta x_m}\right] + \frac{\rho_m c_m T_i^o \Delta x_m}{\Delta t} \ldots (5)$$

The above-mentioned discredited equations are applicable to volume cells(2),(3),(4),(7),and for (10),(11),(12) for roof top slab ,PCM panel and concrete slab ,respectively.m=1,i=2,3,4; m=2 , i=7; m=3, i=10,11,12. See Fig.(3.2)

Interface node

The equation for the interface volume cell 5 is written as follows [16]

$$-\frac{f k_1}{\delta x_1} T_4 + \left[\frac{\rho_1 c_1 \Delta x_1}{\Delta t} + \frac{f}{\delta x_1/2k_1 + \delta x_2/2k_2} + \frac{f k_1}{\delta x_1}\right] T_5 - \left[\frac{f}{\frac{\Delta x_1}{2k_i} + \frac{\Delta x_2}{2k_2}}\right] T_4 = (1 - f)\left[\frac{k_1(T_6 - T_5)}{\delta x_2} - \frac{k_1(T_5 - T_4)}{\delta x_1}\right] + \frac{\rho_1 c_1 T_5^o \Delta x_1}{\Delta t} \ldots (6)$$

WhereΔx_1andΔx_2 are the cell thickness of the roof top slab and PCM panel, respectively. Similarly the equation can be written for volume cell (6).The same procedure is extended to control volumes (8) and (9) which involves cell thickness$\Delta x_2$and Δx_3that corresponds to PCM panel and bottom concrete slab, respectively.

Interior node

The equation for the bottom volume cell 13 is written as given below (vadaiappa et al., 2006).

$$\frac{-f K_3}{\delta x_3} T_{12} + \left[\frac{\rho_3 C_3 \Delta X_3}{\Delta t} + \frac{f k_3}{\delta x_3}\right] T_{13} = f[h_i(-2)] + (1 - f)\left[2h_i - k\frac{(T_{13} - T_{12})}{\delta x_3}\right] + \frac{\rho_3 c_3 T_{13}^o \Delta x_3}{\Delta t} \ldots (7)$$

Computational procedure for roof

The governing equations along with the boundary conditions are discretized using semi-implicit control volume formulation. The region of analysis is divided into

Table 1. property of PCM

PROPERTY	(N-EICOSENE)
Tm	37℃
cps	2.21kj/kg.℃
cpL	2.21kj/kg.℃
Ks	0.51 (w/m.k)
KL	0.22 (w/m.k)
ρ s	856 kg/m^3
ρ L	778 kg/m^3
αL	9.59*10^{-8}(m^2/s)
αs	7.92*10^{-8}(m^2/s)
H	247kj/kg

Table 2. Material property (Ravikumar and Pss.srinivasan, 2008)

Material	**Thermal conductivity(W/m.K)**	**Density(kg/m3)**	**Specific heat(kJ/kg)**
Concrete	1.28	2300	1130

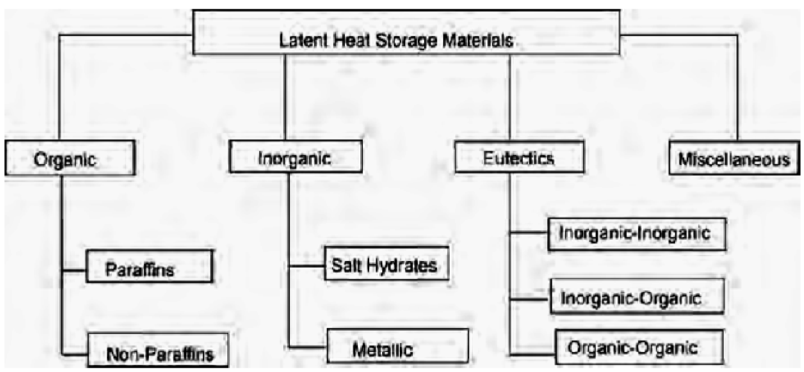


Figure 1. Classification PCMs

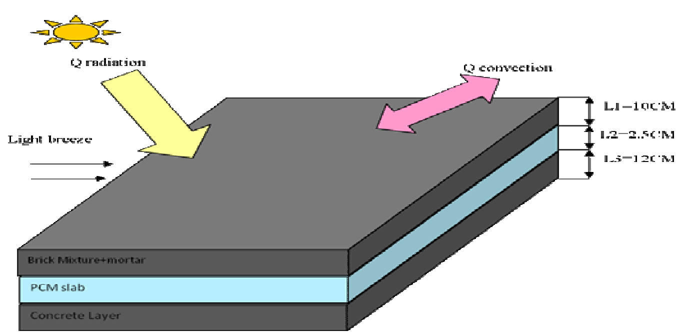


Figure 2. A schematic of Incorporation of PCM Material In Ceiling

five control volumes for each material top and down ceiling while panel three control volumes . A time step of 2 s is used within the simulation. The system of equations is solved using tridiagonal matrix algorithm (TDMA). The solution methodology is explained in the flow chart as shown in Fig(3.3). The initial temperature values are obtained by executing the program, continuously for few days till the routine daily variation attains the same value.

Experimental investigation

Experimental set up consisting of two identical test rooms (1.80m 1.80 m × 2.44 m) shown in Figs. (5) constructed to study the effect of having PCM panel on the roof of the

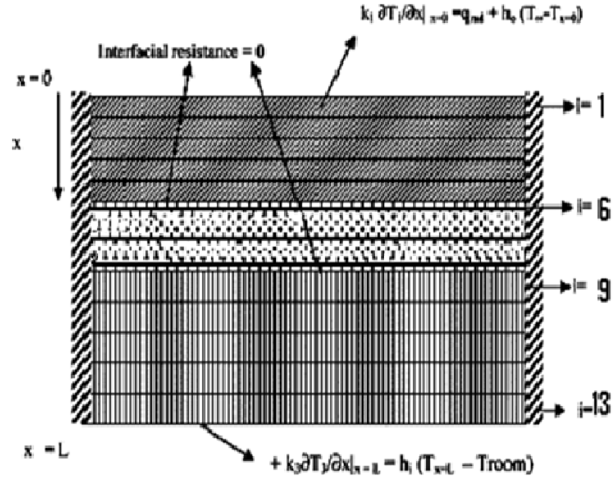


Figure 3. Finite volume grid for the analysis.

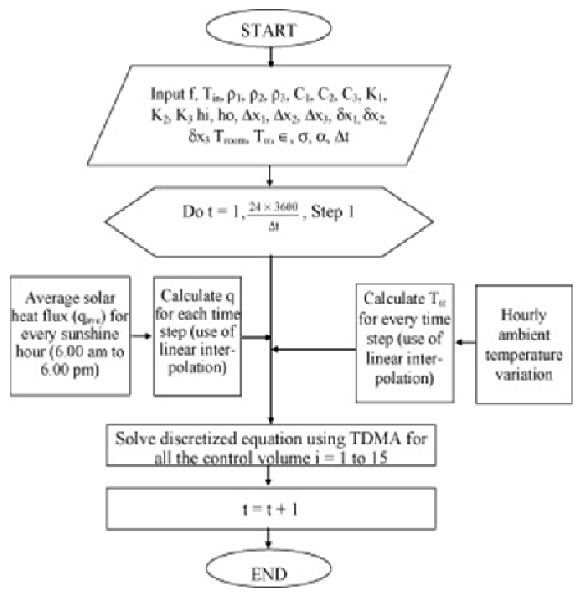


Figure 4. Flowchart

building. One room is without PCM and the other one has PCM panel in between the bottom concrete slab and the roof top slab. Thus it is possible to study the thermal performance of the PCM embedded ceiling over the conventional one. The inner walls except ceiling of the rooms are insulated by wood of thickness 6 mm on all the sides to study the sole effect of PCM panel on the roof and contented door in two room (174cm 67cm)location thi-qar city of Iraq . The ceiling water panels belong to a new type of equipment which is mainly used to provide the cooling of office buildings. The ceiling panels which are an alternative to classic air conditioning systems, enable to improve thermal comfort .As well as for a radiant floor, this system can be used for heating in winter and cooling in summer.

The properties of the PCM used for testing

The PCM panel is made up of aluminum of 2 m by 2 m and thickness of 2.54 cm (Δ=1.0mm ,$k = 206$ W/m℃) which accommodates organic paraffin .This PCM is stored in a closed aluminum metallic container of capacity 0.1 m^3. It is important to note that the container must always be in a closed-sealed system in order to maintain the PCM product integrity. Property given in Table (1). Excess moisture can change the composition of the product and hence it must be airtight. The PCM slab has water pipes inside it which act as heat exchanger and has the following specification. Figs.(6),(7)

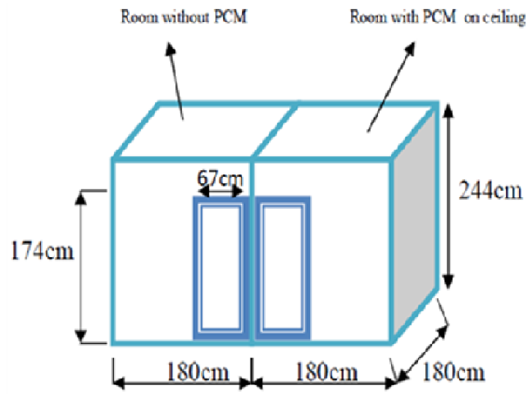


Figure 5. Dimension of two buildings

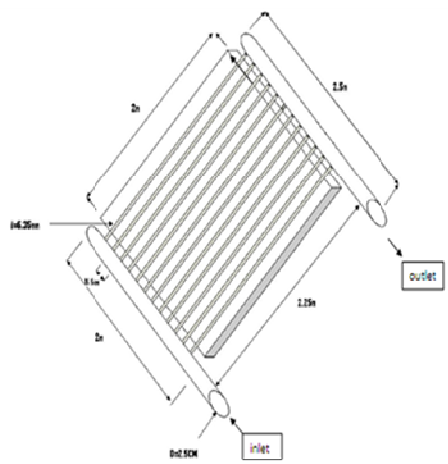


Figure 6. Panel dimension

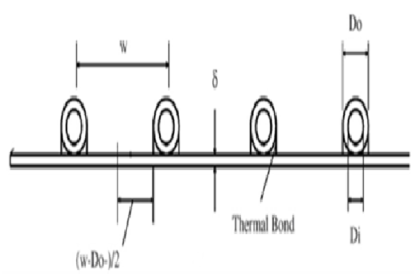


Figure 7. Distrubtion pipeng

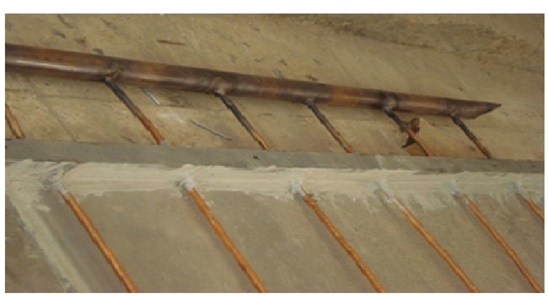


Figure 8. Header pipe connected with piping.

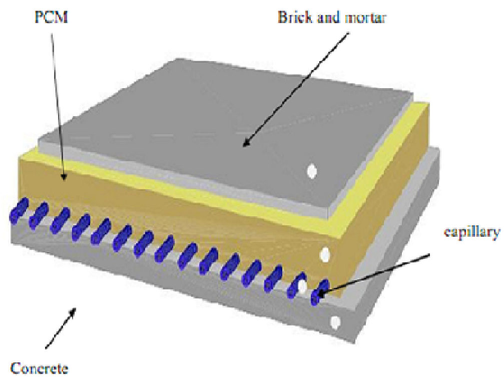
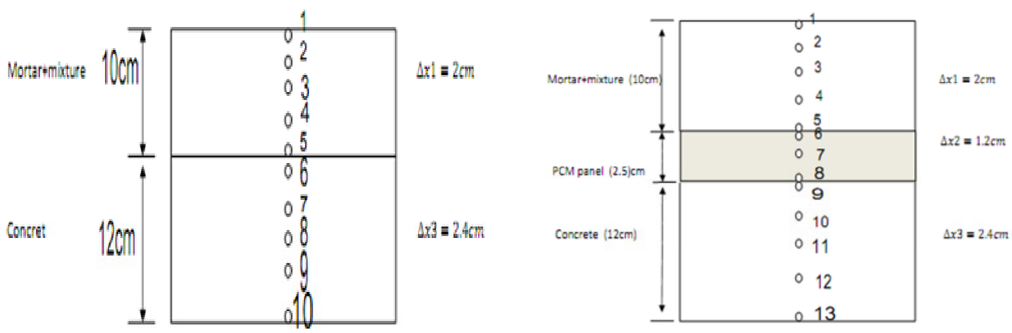


Figure 9. Panel above ceiling(concrete).



(a) **(b)**

Figure 10. Distribution of thermocouples though two types of roof
(a) Without PCM
(b) With PCM

- Tube material: copper.
- Length of the tube: 2.25 m.
- Tube diameter: Do=6.35 mm. Di=5.74mm
- Number of tubes: 12.
- Distance between tubes w=16.6mm

The tubes are connected on both sides to a copper header that has 2.5cm diameter and 2.5 m length, each have a length of 2.5 m, Fig(8).The water flow velocity through header v=0.34m/s, mass flow rate $\dot{m} = 0.16\text{kg/s}$,and for capillary tube$\dot{m} = \frac{0.013kg}{s}$. Renoldnumber (Re= ρuD/μ is Re=8673.4. The total mass of the PCM mixture used is 78 kg, which, in its liquid state is poured into the panel submerging the heat exchanger pipes, and the whole assembly is sealed properly. The PCM panel put above ceiling is shown in Figs(9).A water tank with a capacity of 200 L is kept at the bottom and a pump is used to circulate cold water through the PCM panel heat exchanger, when required . This water is used to cool the PCM when the complete freezing of PCM is not possible in the night hours during the summer. If the PCM does not freeze until early morning of the next day, it may not be ready for next cycle of operation. Under such situation, the cold water is to be circulated through the water tubes until the PCM is solidified. In addition, during peak summer in day time when the temperature of the PCM starts increasing above its melting temperature, cold water is to be circulated through the tubes to maintain constant temperature (i.e., around PCM melting temperature).

The Measuring parameters

The RTD (resistance temperature detector)(Type k) is placed in different locations show in Fig(10) with the room with PCM five sensors for concrete slab , three sensors for panel and five for roof top slab. For the room without PCM: Five detector for concrete slab ,five detector for top slab with perfect sealing as shown in Figs(11). Two thermocouples fixed inside the header ,one upstream and the other downstream. This thermocouple is joined with

Figure 11. Thermocouple inside concrete slap

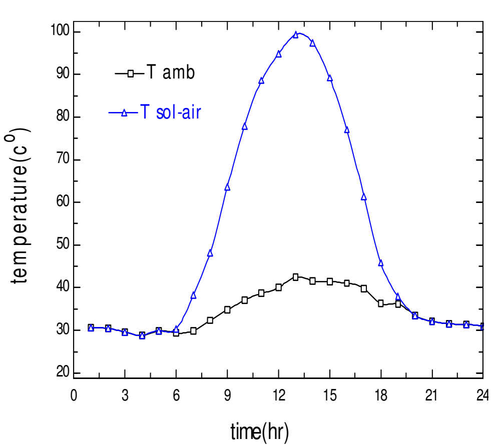


Figure 12. Graph between the Time vs T_{amb} and Time vs $T_{sol-air}$

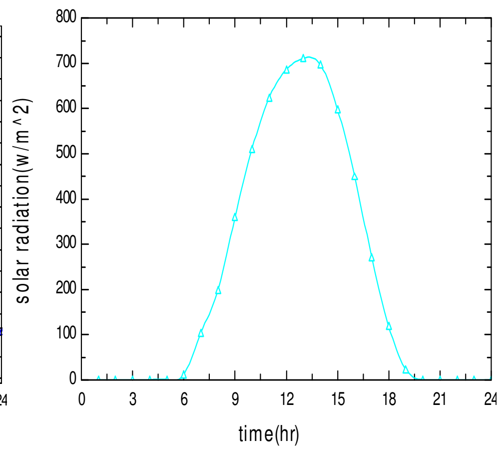


Figure 13. Solar radiation data for Baghdad during August 2000.

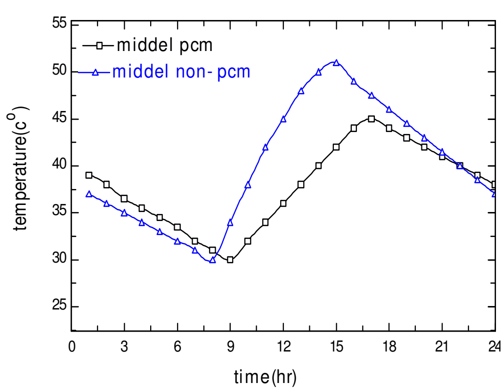


Figure 14. Experimental temperature distribution roof structure

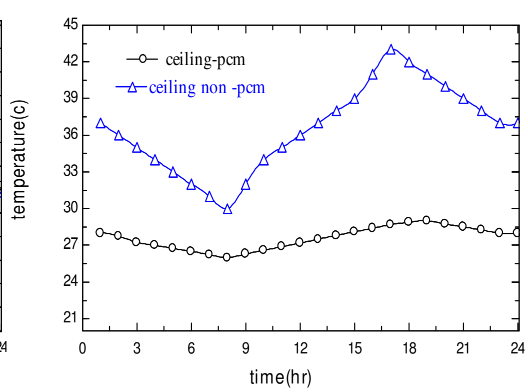


Figure 15. Experimental temperature theacross the ceiling in the PCM and non –PCM room

digital reader (vichy).The pump device is used for circulation of water and the flow meter device (model:lzzs ,flow range (1-9) Lpm) used to measure volume flow rate of water, flow rate can changed by control gate valve.

Experimental procedure

- The measurement devices were purpose to take measuring where sensors were installed inside the ceiling

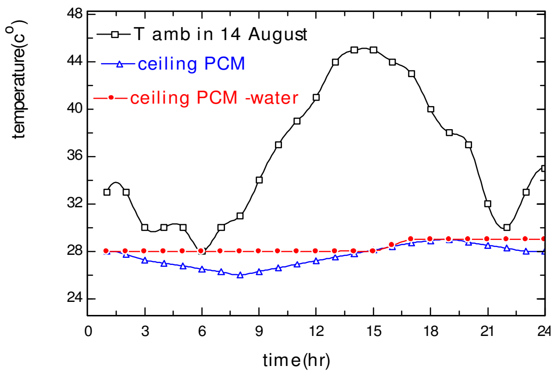


Figure 16. Experimental investigation of the PCM through August with water circulation.

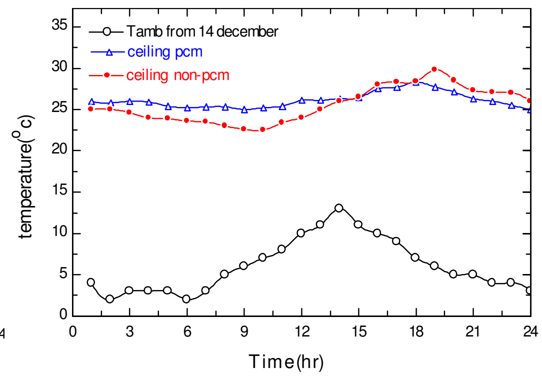


Figure 17. Experimental investigation of the room PCM room through 14 December .

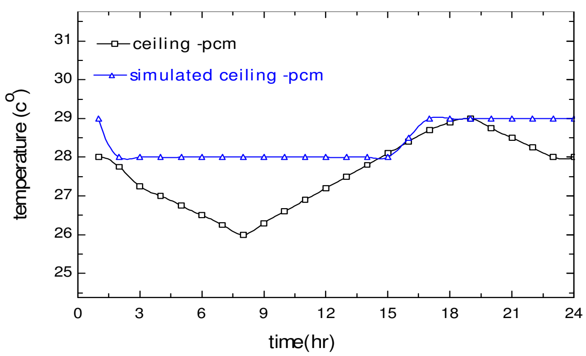


Figure 18. Experimental and simulated temperature of the pcm.

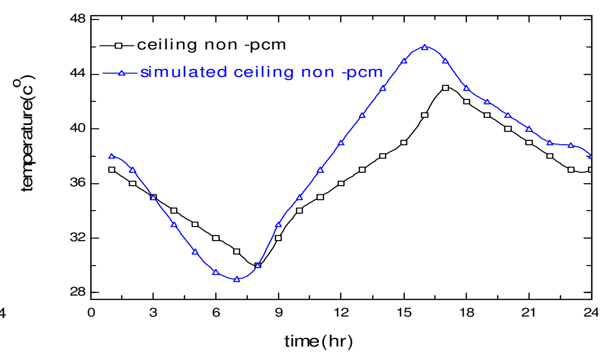


Figure 19. Experimental and simulated ceiling in the temperature of the ceiling non-PCM room

and rooms with selector connected digital reader.

- The measurement was taken for 24 hours beginning at 8 A.M. For two different month August and December 2010.
- All measurement taken in every hour in day done this state without water through ceiling.
- Done now insert water through piping of PCM panel with different range taken measurement in this state also all hour.

Roof types

The two roof structures taken in study are as follows:
Roof -1without PCM. Content two layers: roof bottom slab of concrete with thickness 12cm and roof top slab content (brick mixture + mortar) thickness 10 cm. The thermal conductivity of the concrete slab and the roof top slab are considered constant and not varying with respect to temperature.
Roof -2 with PCM.Content three layers: roof bottom slab of concrete with thickness 12cm , roof at middle structure panel from aluminum full PCM thickness 2.5cm roof top slab content (brick mixture + mortar) thickness 10 cm .The property of top slab and bottom slab are given in Table (2) .

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RESULTS AND DISCUSSION

Solar insulation and weather data of Baghdad during Augusts used. $T_{sol\text{-}air}$ are found out by using the formula [3] {$\mathbf{T_{sol} = T_{amb} + (\alpha q_s / h_0)}$}.The graph between the Time vs. T_{amb} (See appendix B) and Time vs. $T_{sol\text{-}air}$ is plotted as shown in the Fig.(12) . The solar radiation data Baghdad during Aug. 2000(See appendix A) is recorded as shown in Fig (13). The thicknesses of both two roof structures are different, so the distance is normalized ($Y^*=Y/Y_{max}$) with Y=0, Y*=0 referring to the bottom of the roof and $Y=Y_{max}$ and Y*=1.0 referring the top surface of the roof. The maximum temperatures are around 48^0C and the minimum around 38^0C, and maximum solar radiation around 700w/m^2. Temperature distribution across the roof structure is shown in Fig.(14). For the roof of type 1 at the surface at τ =0 hr to τ =6 hr, there is no solar radiation on the building surface. But the heat

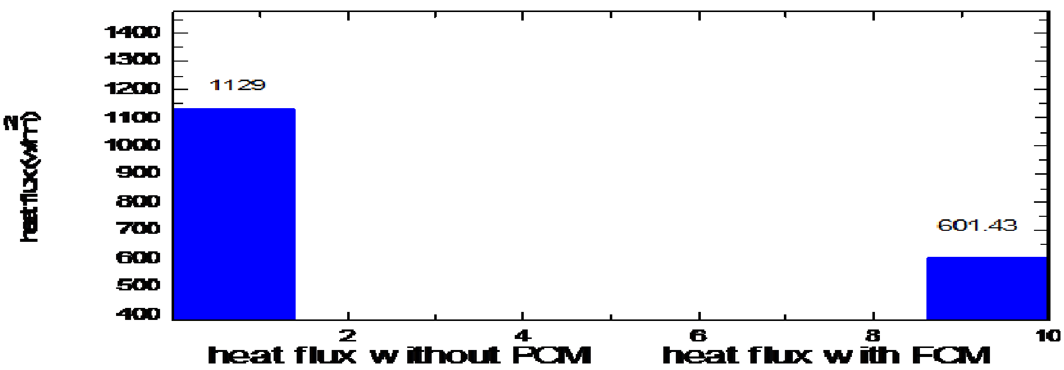

Figure 20. The simulated heat flux enter into the room

Nomenclature

C1, C3	specific heat of roof top slab and concrete slab	(kJ/kg K)
cpl	specific heat of liquid PCM	(kJ/kg K)
cps	specific heat of solid PCM	(kJ/kg K)
f	implicit factor	
GrL	Grashof number	
hi	inside heat transfer coefficient	(W/m2 K)
ho	outside heat transfer coefficient	(W/m2 K)
k1, k2, k3	thermal conductivity of roof top slab, PCMpanel and bottom concrete slab	(W/m K)
L1, L2, L3	thickness of roof top slab, PCM panel andbottom concrete slab	(m)
NuL	Nusselt number	
Pr	Prandle number	
qrad	radiation flux	(W/m2)
Re	Reynolds number	
T	temperature	(c°)
T_∞	ambient temperature	(c°)
T_i^0	previous time step temperature at volume cell	(c°)
T_i	current time step temperature at volume cell	(c°)
Tin	initial temperature	(c°)
Troom	room temperature	(c°)
Ts	surface temperature	(c°)
Tsky	sky temperature	(c°)
α	absorptivity	
ϵ	emissivity	
hsl	solid–liquid enthalpy change	(kJ/kg)
σ	Stefan Boltzmann constant	
q1, q2, q3	density of roof top slab, PCM panel and bottomconcrete slab	(kg/m3)
Δt	time step	(s)
$\delta x1$, $\delta x2$, $\delta x3$	nodal distances	(m)
$\Delta x1$, $\Delta x2$, $\Delta x3$	control volume length of roof top slab, PCM panel, bottom concrete slab	(m)

accumulated in the structure travels on both the sides of the roof. The temperatures at the top and bottom surfaces are lower compared to the temperature inside the roof. The average temperature for the concrete structure is the highest among all the other types of roof as the thermal conductivity of type 1 ismore compared to the roof of type 2. As the thermal conductivity of the roof of type1 is higher, more heat will be stored during the previous day. The thermal conductivity of the roof of type2 is low compared to type1. The curve for the roof of type1 falls below the other curve because PCM absorbs maximum heat energy passing through the roof.

At τ =6 hr to τ =12 hr, as the solar radiation falls on the surface, the heat transfer characteristics increases varying from the previous time period. As the thermal conductivity of the roof 1 is high, whatever the heat enters, all the heat transferred to the bottom so the curve is linear and average. The curve for the PCM reaches the least value at the bottom and it reaches the peak value in the top layer.At τ =12 hr to τ =18 hr, the rate of solar radiation falling on the roof decreases but the heat that has already entered travels inside the roof. The mid plane temperature values are higher than the τ =12 hr. As the heat flux during this τ =18 hr has very small value, so the convection at the roof top dominates during this period. Compared to the Roof 1, Roof 2 has reduced the temperature at the bottom of the roof by 12º.

During τ =18 hr to τ =24 hr, there is no solar radiation entering the roof. So the temperature at the top and bottom of the roof is nearly the same. For the Roof 2, temperature reaches peak value at the middle and in the region where PCM is located, temperature falls suddenly to room temperature as the PCM absorbs all the heat passing through the roof. And it reaches almost least value at the bottom as the PCM installed region acts as thermal energy storage.Fig.(15) show the temperature variation of the roof in the PCM and non-PCM rooms varies. From the experimental results, a small decrease in ceiling temperature during the day time and small increases in ceiling temperature during the night time observed where reduces the fluctuation of temperature inside the PCM room. This is due to the large heat storage capacity of the PCM. On the other hand, a large fluctuationis observed in the ceiling of the non-PCM room as the outside environment immediately influences the ceiling of the non-PCM room.The effect of water supply through the tubes embedded in the PCM panelcan be shown in Figs (16 and17) through August and December.

In the present experimental investigation, water is allowed to pass through the tubes in the PCM panel to extract the heat at a faster rate. This experiment was conducted during the month of December and the results are shown in Fig.(16) for the PCM room with and without water circulation. The water is passed through the tubes for duration of 30 min around 1600 h. A marginal decrease in ceiling temperature is observed. However, this effect must be appreciable during summer. In the theoretical investigation during month of Augusts around 1600 h, the temperature of the PCM is suddenly decreased by 1^0C, which represents the removal of latent heat from the PCM .Therefore, the bottom surface temperature of the concrete slab is maintained at a constant level of 27 ^{0}C The quantity of water required to extract the latent heat from a unit surface area is calculated as. such a large quantity of cold water per unit area is not easily available during the summer period.

In Fig. (17) in the month ofDecember observed in the non-PCM room ceiling (concrete) variation with time while ceiling PCM is stability with daily rang . This is due to the high thermal mass in the PCM and the storage of solar heat gains as latent heat in the PCM while in the non-PCM room the storage of solar gains as sensible heat results in an increase of the ceiling temperature. However the ceiling temperature in the PCM room attainsthough the introduction of PCM helps in achieving a constant temperature at the ceiling during the month of December.

Comparison of results

A computer program is used to compare the two-dimensional flows within natural convective model with and without PCM in the roof. The simulations consist of two parts, the first one deals with the roof when the governing equations along with the boundary conditions are discretized using semi- implicit control volume formulation. The region of analysis is divided into multi control volumes for each material. A time step of 2 s is used within the simulation. The system of equations is solved using tridiagonal matrix algorithm (TDMA). The initial temperature values are obtained by executing the program, continuously for few days till the routine daily variation attains the same value. From the step the temperature for the ceiling will be obtained. comparison between present calculations and experimental result obtained in chapter three for temperature of the ceiling in the PCM and non-PCM room for two cases with and without PCM in the roof. It is seen from the Figs(18and19) that the ceiling (concrete) temperature of the PCM room in the numerical analysis is maintained at a constant value of 27^0C throughout the day. This shows that the environment has little effect on the inner surface of the ceiling as all the heat energy is absorbed by the PCM kept in the roof. On the other hand, a large fluctuation is observed in the ceiling of the non-PCM room as the outside environment immediately influences the ceiling of the non-PCM room. From the experimental results, a small decrease in ceiling temperature during the day time and small increase in ceiling temperature during the night time is observed which reduces the fluctuation of temperature inside the PCM room. This is due to the large heat storage capacity of the PCM. Further, it is observed that the temperature difference of the ceiling in the PCM and non-PCM rooms is not very appreciable as in the theoretical results. The differences in temperature value between the theoretical and experimental results are due to the following reasons.

• The ceiling of the roof is influenced by the inside room condition where an actual temperature variation.

• The effective thermal conductivity of the PCM in the experiment is higher due to the presence of uniformly distributed high conductivity heat exchanger material in

the PCM panel.
• The actual phase change may not occur during the phase change temperature prescribed in the theoretical analysis.

The simulated results are not in good agreement with the experimental results due to the above mentioned reasons. The simulated heat flux entering into the room is shown in Fig.(20), it clearly states that PCM installed roof is better than the roof without PCM. If the roof is installed with PCM it can reduce the heat entering the room about more than two-third than the roof without PCM. Comparing between roofs with the roofs with and without PCM, we fined PCM reduces the heat transfer by 46.71%. The reduction in heat transfer is directly proportional to the corresponding reduction in the electrical energy consumption to maintain the room at 25ºC.

CONCLUSIONS:

An experimental facility for the study the effect of the use phase change materials (PCM) in buildings has been designed, constructed and tested. The flexible facility makes it one-of-a kind full- scale structure for the study of room with and without PCM in the roof. Also the following conclusions can be drawn from the computational modeling techniques investigated throughout this research.

1- The heat entering in to the room is maximum with roof without PCM, because the thermal conductivity of this type of roof is of high value. So almost all the heat entering the roof was transferred to the room. When roof contains with PCM laid roof the heat entering the room is reduced by 46.71%.As the PCM has low thermal conductivity, it offers the resistance to the heat flow and heat transfer is reduced by 46.71% compared to the roof without PCM.

2- The effect of variation in the ambient condition is for all the months,. In addition, the effect of water circulation through the PCM panel is also attempted for the thermal management during summer months. It is observed from the study that the quantity of water required is very large which is not easily available during the summer months.

3- Numerical studies show a significant reduction of indoor air temperature for buildings without mechanical cooling and downsizing potential as well as reduction of peak-load power and energy consumption for buildings with mechanical cooling equipment. However, latent thermal storage only performs well if the storage is periodically being discharged either by natural cooling or by mechanical cooling sources during the time of lower cooling load.

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